University of Illinois at Urbana-Champaign
Dept. of Electrical and Computer Engineering

ECE 120: Introduction to Computing

Pareto Optimization*

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What's Best When We Have Several Metrics?

As engineers, you will rarely have the luxury
of a single metric.

How does one choose between metrics?

Imagine the following …
◦ You are working as an intern
◦ designing hardware to execute DNNs
  (dense neural networks, which may be
  useful in a variety of tasks).

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Example: Compare Designs Based On Area and Delay

Building on your ECE120 knowledge,
you have two metrics.
◦ **Area**, which you have normalized
  from **1 to 100**.
◦ **Delay**, which you have also normalized
  from **1 to 100**.

In both metrics, **smaller is better**.

For a design X, $A(X)$ **is the area**,
and $D(X)$ **is the delay**.

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Which Metric is More Important?

Now imagine that you have
two designs, X and Y.

How do you choose between them?

Which is more important, area or delay?

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The Answer Depends on How the Design is Used

The answer **depends on the context** in
which your design is used
◦ datacenter
◦ laptop
◦ mobile phone
◦ car or other vehicle
◦ space probe
◦ children's toy

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One Option is to Combine Metrics Numerically

How do you make a choice?

One option: **linearize**. Pick some weights
◦ actually, one weight **W** is enough
◦ **W** is the **relative importance**
  of delay compared to area

Then
◦ for each design **X**
◦ calculate **M(X) = A(X) + W D(X)**

Choose the design with the smallest M(X).

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Relative Importance is Not Easy to Choose in Practice

But how do you pick **W**?

What if you need designs for
ALL of those applications?

As an engineer, you may not be in a position
to know the right weights!

So **what can you do if you don't know the
relative importance of the metrics**?

For two designs, probably
just report both to your manager.

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Remember Dilbert? Oxygen is Good.

What if you have created 10,000 designs?
◦ Not by hand, but by using parameters.
◦ For example, does your design provide
  hardware for 8-bit, 16-bit, 32-bit, or 64-bit
  addition?

Do you report all 10,000 to your manager?
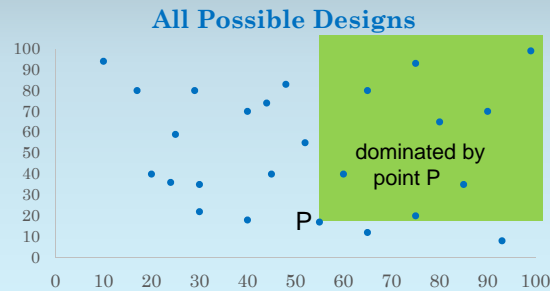Probably not if you want a job offer.

But **what can you do**?

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A Design that is Worse in All Metrics is Pareto-Dominated

Pick two designs **X** and **Y**.

What if **A(X) < A(Y)** AND **D(X) < D(Y)**?

Remember that smaller is better
for both area and delay.

In such a case, **do you need to report Y**?

No! **X** is better in both metrics.

We say that **design Y is
Pareto-dominated by design X**.

If there were **N** metrics, **Y must be worse
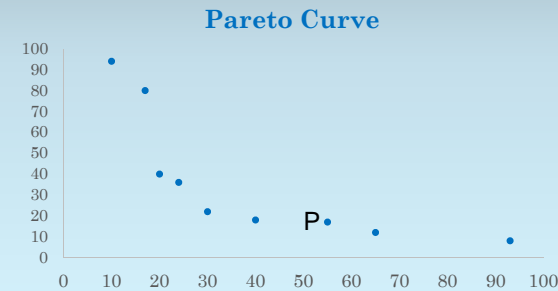than some X in ALL metrics to be
Pareto-dominated**.

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Eliminate Designs that are Pareto-Dominated by Others

You can use the idea of Pareto domination to
eliminate designs.

Any design that is Pareto-dominated
by any other design **can be discarded**.

Only designs that may be better in some
context remain.

The remaining designs form a **Pareto curve**
(a Pareto surface for more than two metrics).

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A Graph Illustrates Pareto-Dominance (Small is Good)

All Possible Designs

dominated by
point P

P

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A Pareto Curve (after Discarding Dominated Points)

Pareto Curve

P

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Use of Pareto Curves/Surfaces is Common

In many hardware design environments,
engineers run **design-space exploration**
tasks (on computers, of course!):
◦ Given a set of parameters for a design
◦ Generate hardware for each possible
  combination of parameters
◦ Then use Pareto dominance to
  trim the results down
◦ And show the engineer the Pareto surface of
  area, delay, and power consumption.

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Want to Learn More about Optimization?

Take ECE490 some day.

Combines theory and practice:
◦ optimization algorithms,
◦ Implementations,
◦ use of libraries to solve problems.